

## Characterization of GW-class Isolated Attosecond Pulses Based on All-optical FROG

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A custom-tailored fully stabilized three-channel multi-TW waveform synthesizer with 10-Hz repetition [1] is developed to realize sub-microjoule gigawatt-scale isolated attosecond pulse (IAP) with duration of  $\sim 226$  as demonstrated by frequency-resolved optical gating for complete reconstruction of attosecond bursts (FROG-CRAB) [2]. In this work, based on this waveform synthesizer, intense IAPs centered at photon energy of 60 and 107 eV are generated and characterized by an all-optical metrology [3]. In comparison with conventional FROG-CRAB, this method, requiring no central momentum approximation assumption nor e-TOF based complicated setup, exhibits a much simplified and faster, while robust approach for IAP characterization especially for low repetition systems.

As shown in Fig.1, the HHG process would be perturbed by a synchronized multi-cycle weak gating field ( $<10^{-3}$  in intensity ratio). By employing a FROG-like gating mechanism between the driving and gating fields, the delay time dependence of HHG spectra is recorded, which reflects the electron recombination phase modulated by the gating field. Correspondingly, as shown in Fig.1(b), the temporal distributions of IAPs are retrieved with the Least Squares Generalized Projections (LSGP) algorithm, yielding the pulse width of  $\sim 227$  and  $\sim 148$  as at the center photon energy of 60 and 107 eV with reconstruction error as low as 1.89% and 2.68%, respectively. The results are in accordance with the ones from FROG-CRAB, showing considerable reliability. Moreover, the exposure of less than 2 seconds for each delay step is enough to obtain a high signal-to-noise ratio in our experiments (even single-shot in theory), which significantly reduces the FROG trace acquisition time to only a few minutes.

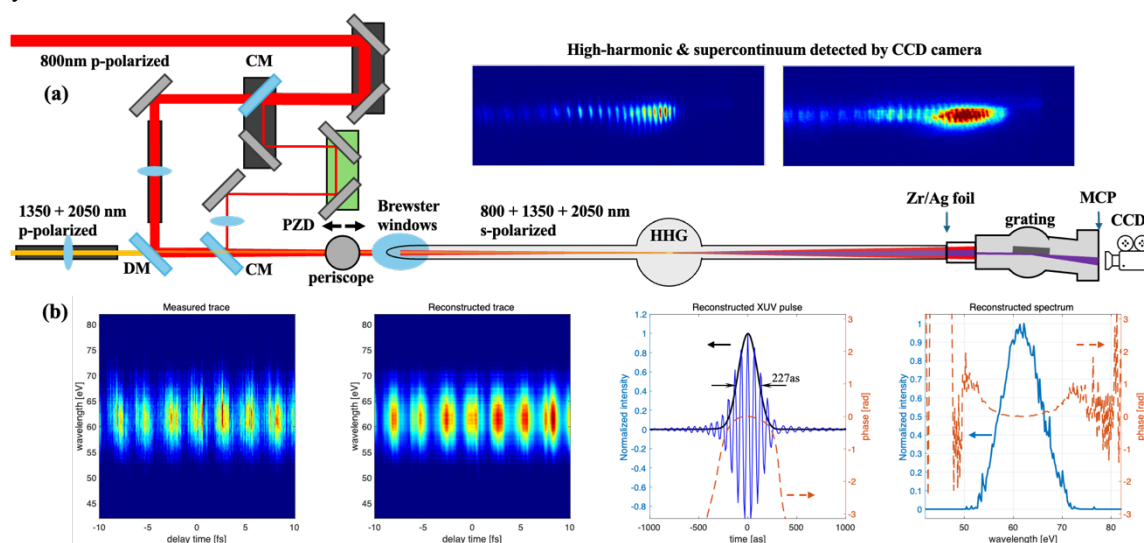


Fig. 1. (a) System set up and experiment results of All-optical FROG; (b) Result of GW-class IAP@ 60eV from Argon gas.

[1] B. Xue, Y. Tamaru, Y. Fu, et al., Sci. Adv. 6, 16, eay 2802 (2020)

[2] B. Xue, K. Midorikawa, E. J. Takahashi, Optica 9, 360-363 (2022)

[3] Z. Yang, W. Cao, X. Chen, et al., Opt. Lett. 45, 567-570 (2020)